NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

WASHINGTON, D C

CONTRACTOR FINAL REPORT

TEST #

151

DOT HS-803 707

151 AFS

EVALUATION OF RESEARCH ON SURROGATES FOR HUMANS IN MOTOR VEHICLE CRASHES

Assembly of Life Sciences
National Academy of Sciences
Washington, D.C.

Contract No. DOT HS-8-01948
Contract Amt. $39,700

JUNE 1978
FINAL REPORT

Prepared For
U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No DOT-HS-803 707	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle Evaluation of Research on Surrogates for Humans in Motor Vehicle Crashes		5. Report Date June 1978 6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No
9. Performing Organization Name and Address Assembly of Life Sciences National Academy of Sciences Washington, D.C.		10. Work Unit No (TRAIS) 11. Contract or Grant No DOT-HS-8-01948
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 400 7th Street, N.W. Washington, D.C. 20590		13. Type of Report and Period Covered April 1978-June 1978 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A review of the current status of automobile crash research utilizing cadavers, volunteers, animals, and models was conducted. The aim of the review was to determine the necessity for utilization of cadavers in such research. All viable alternatives were examined and it was the unanimous view of the committee that the National Highway Traffic Safety Administration could not develop essential information for crash safety rulemaking without resorting to the use of cadavers in certain types of crash research.

17. Key Words	18. Distribution Statement
Cadaver, Human Surrogate	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif (of this report)	20. Security Classif (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	55	

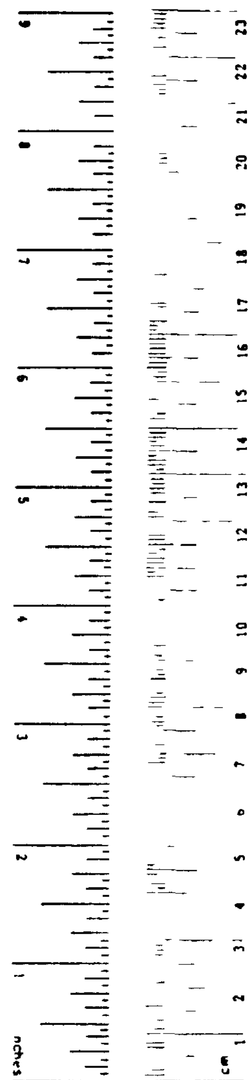
Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

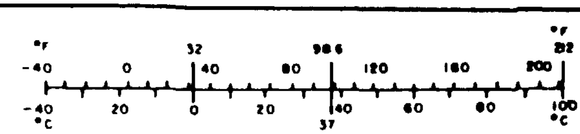
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

[illegible]



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The work on which this publication is based was performed pursuant to Contract No. DOT-HS-8-01948 with the U.S. Department of Transportation.

PREFACE

The Committee on Evaluation of Research on Surrogates for Humans in Motor Vehicle Crashes, established within the Divison of Medical Sciences, Assembly of Life Sciences, National Research Council, was asked:

- o to review the current status of research with cadavers, volunteers, animals, and alternative research systems in the development of surrogates which are used to develop safety devices and restraints designed to reduce the mortality and morbidity associated with automobile crashes and to test their effectivenss; and,
- o to evaluate the current research and recommend directions for future research in the field.

The committee was specifically requested to examine and assess the following categories of research:

- o the National Highway Traffic Safety Administration (NHTSA) approach to the development of anthropomorphic dummies with respect to NHTSA's goals and within the context of NHTSA's legal and engineering prerogatives and responsibilities;
- o the ability of this program to achieve NHTSA's goals;
- o the utility of human cadaver testing or other major testing modes on the quality and timeliness of achieving these goals;
- o alternative approaches that are considered to be capable of producing feasible, timely, and practical solutions to the problem of anthropomorphic dummy development; and

the adequacy of the procedures for acquisition and description of medical data, engineering data, and analytical procedures, and alternative procedures that might permit the elimination of cadaver research

The committee has addressed each of the issues encompassed by its charge. It is grateful for the complete presentations and free and open discussions by the staff of NHTSA at a workshop session which formed a basis for its examination. (See Annex A) Views of other workers in the field were also solicited. Their contributions are gratefully acknowledged

The committee's report provides a review and commentary on current research followed by a description and evaluation of each major research approach and statements regarding the relationship among the several different approaches. The committee's recommendations appear in the Summary which precedes the body of the report.

The committee wishes to acknowledge the National Highway Traffic Safety Administration, U. S. Department of Transportation, for its financial support of this study.

Ayub K. Ommaya, M.D.
Chairman

COMMITTEE ON EVALUATION OF RESEARCH ON [1] HUMAN SURROGATES IN MOTOR VEHICLE CRASHES

AYUB K. OMMAYA, National Institutes of Health, Bethesda, Maryland, Chairman

BRIAN D. BLACKBOURNE, Office of the Chief Medical Examiner, Washington, D.C.

THOMAS D. BROWER, University of Kentucky, Lexington, Kentucky

ARTHUR A. EZRA, National Science Foundation, Washington, D.C.

EDWARD H. HARRIS, Tulane University, New Orleans, Louisiana

ROBERT L. HESS, The University of Michigan, Ann Arbor, Michigan

WILLIAM F. McCORMICK, University of Texas Medical Branch, Galveston, Texas

JOHN E. McDERMOTT, American Academy of Orthopedic Surgeons, Seattle, Washington

GERALD W. NYQUIST, General Motors Corporation, Warren, Michigan

T. FRANCIS OGILVIE, The University of Michigan, Ann Arbor, Michigan

RANDALL W. SMITH, University of California Hospital, San Diego, California

Resource Guests

STAFF, National Highway Traffic Safety Administration, U. S. Department of Transportation

RAYMOND F. NEATHERY, Oklahoma State University, Stillwater, Oklahoma

RICHARD F. CHANDLER, Civil Aeromedical Institute, Federal Aviation Administration, Oklahoma City, Oklahoma

***

DANIEL L. WEISS, National Academy of Sciences - National Research Council, Staff Officer

[1] Committee members and guests represented themselves, not their employers or the agencies with which they are affiliated.

TABLE OF CONTENTS

SUMMARY

The Committee on Evaluation of Research on Surrogates for Humans in Motor Vehicle Crashes has reviewed the research activities sponsored by the National Highway Traffic Safety Administration (NHTSA), U. S. Department of Transportation, with especial attention to the programs directed towards motor vehicle crash and injury analysis. The ultimate objective of the NHTSA program under examination is to reduce human injuries and deaths in motor vehicle accidents.

Since improving the quality of safety on the road involves problems other than the development of crashworthy vehicles, the committee has briefly alluded to other issues in order to place the vehicular modification program into a broader perspective. In terms of automotive safety, the relative values of the broader issues cannot be addressed in detail because time constraints did not permit a thorough analysis. However, the committee has presented some value judgments regarding the practicability and possible outcomes of such broad areas as modification of driver behavior and highway improvement, the two subjects which are collateral to this specific study.

The committee has assessed the advantages and deficiencies of each of the major approaches to vehicular modification. Its conclusions are embodied in a set of recommendations set forth below. An expository section that deals with the subject of multiple research approaches used interactively appears at the end of the report (page 24). It should be read in conjunction with the recommendations.

RECOMMENDATIONS

1. Continuation of research toward the development of increasingly crashworthy motor vehicles should be actively and aggressively pursued. The current rate of accidents that result in death and major injury is unacceptably high and should be substantially reduced.

2. The three general areas in which substantial continuing research is required are the driving behavior of the American public, highway safety engineering, and modification of motor vehicles to improve their crashworthiness and to increase the quality of their safety systems to reduce death and injury.

3. The approach to vehicular modification cannot be confined to any one methodology since each has advantages and shortcomings that must be supplemented by the others. The methods that must be employed to develop an adequate understanding of the relationships between the motor vehicle and its occupants and between motor vehicles and pedestrians include:

- retrospective field analyses of accidents,
- studies with volunteers at levels of dynamic loading that produce no or minimal injuries,
- development of more realistic anthropomorphic dummies to be used in crash tests for vehicle development and certification,
- studies with human cadavers to provide a basis for surrogate development and validation,
- studies with animals, both living and cadaveric, and mathematical modelling.

4. Consideration should be given to the development of programs to instrument significant numbers of production motor vehicles to obtain more accurate and useful data on the physical characteristics of crashes that occur in everyday use.

5. Consideration should be given to the development of programs that will place specifically and selectively modified motor vehicles in the hands of the driving public to evaluate the effects of such modifications on safety. Such programs will require that the public is not denied any standard device that provides an acceptable form and level of protection.

6. To provide a data base for the development of anthropomorphic dummies and injury criteria, the use of human cadavers is necessary and should be continued.

7. Human cadaveric studies are deemed necessary in vehicle crash tests for which current dummies are insufficient, e.g., to validate the data on such safety innovations as new restraint systems which have been developed in vehicle modification research programs.

* * *

With respect to recommendations 6 and 7, the committee recognizes that certain significant differences exist between a living human occupant in an automobile crash and a human cadaver in a test crash, but it is convinced that human cadaver testing is the most useful and appropriate method of assessing human dynamic response characteristics at injurious impact severities. Furthermore, describing the injury mechanisms and tolerances of the human body to impact loading requires the correlation of data from human cadaveric research with other data sources. Addressing these factors is a prerequisite to surrogate design.

The committee, therefore, after careful study and deliberation, recommends continued use of human cadaveric testing to aid in establishing sound bases for the design of biomechanical surrogates such as improved anthropomorphic dummies, mathematical models, and for the correlation of dynamic load histories[1] with injuries.

The use of cadavers must continue to be limited to necessary experimentation that is conducted under ethical guidelines that preserve the dignity and privacy of the human body.

---

1 Dynamic load history: the load applied to an object over time, in which load is a function of time.

REVIEW OF CURRENT WORK

The goal of NHTSA's research program to reduce injury and death in motor vehicle accidents requires the development of safer motor vehicles and protective systems for the motor vehicle occupant or pedestrian. Extensive and precise information that describes mechanisms of human injury in motor vehicle accidents must be obtained in order to achieve these ends. The identification of structural components of both vehicle and subject that contribute to the injury mechanism are critical to this effort. From such data bases, safer motor vehicles can be designed.

The specific types of questions that must be asked to address this issue include:

- o What are the physical variables in the environment that effect human injury? What is the severity, from a medical point of view, of the injuries?
- o What biomechanical data base is available to describe in physical terms the injury scenario?
- o What specific physical parameters can be extracted from the data base to describe the injury scenario for the purpose of standardization and improvement of safety design concepts?

This information is not available from the current general medical or bioengineering literature in enough detail to be translated into adequate safety systems (Chandler and Christia , 1970; Goldsmith, 1966, 1978). The use of volunteers is largely obviated by the unacceptability of serious injury or death under the conditions of greatest practical concern (a major crash). Laboratory animals are essential for physiological studies, but even higher primates, which most closely resemble humans, are anatomically and physiologically different from humans to the extent that scaling of data from primates to humans has proven to be very difficult (Ommaya et al., 1967; Ommaya and Gennarelli, 1976; Ommaya and Hirsch, 1971; Snyder, 1970). Thus, the experimental subject must:

(a) have the same general structure, mass distribution, geometrical configuration of parts, and anatomical ranges of motion as humans;

(b) respond in a humanlike manner in the areas of greatest vulnerability (head, chest, pelvis) to dynamic loads that produce lacerations, fractures, etc.;

(c) be available for study;

(d) be protected from unreasonable pain, suffering, and disability.

Donated ("willed") cadavers, appropriately instrumented, have been used in a variety of configurations to determine the loads needed to produce skull, femoral shaft and rib fractures, cerebral lacerations, etc., thereby disclosing significant information regarding dynamic mechanical response characteristics, mechanisms of injuries, and injury criteria.

These data, obtained with care and discrimination, have been used to develop safer vehicle-occupant relationships. Moreover, they serve as a basis for the development of anthropomorphic dummies that serve as surrogates for volunteers and for human cadavers (Kryopoulos and Roe, 1970).

The currently available dummies, although useful, are judged to be only minimally humanlike in overall performance under crash situations

(Backaitis and Enserink, 1977; Massing, 1977). Among the many areas needing substantial improvement are the head-brain complex and the vertebral column of the surrogates. Furthermore, investigators need to develop more humanlike chest and abdominal structures, including the internal organs, and to instrument these areas effectively. The torque-angle-time characteristics of human upper and lower jointed extremities must be defined so that more effective dummy counterparts can be developed.

NHTSA-Sponsored Research Projects

A number of specific examples of NHTSA-sponsored research projects, together with their rationale, are summarized below.

NHTSA has sponsored a number of research programs (Annex B) having as goals the development of methodology to predict the levels o injury to humans in specially-configured test situations, each of which represents an important aspect of automobile crashes. Field investigations and detailed engineering/medical case studies have shown that a high proportion of deaths and serious injuries result from the impact of the human head on instrument panels, windshield headers, A-posts, and hard ground surfaces. To develop effective countermeasures, investigators must determine the probable engineering characteristics of the loading pulses on the head and correlate these with injury.

The physical characteristics of the human head are unique determinants of the resultant injury, i.e., a human head reacts differently than an aluminum head (Khalil *et al.*, 1974) or a urethane head (Hodgson, 1972) when striking the same target in a motor vehicle. NHTSA has sponsored the use of human (cadaver) heads in physical testing to develop the proper predictive model to relate nonbiological test devices to design or or test measurements. Statistical correlation between gross kinematic measurements[1] and field data on injury has been used to design rudimentary countermeasures for head injury (SAE, 1975; Snyder, 1970). Because of the crude nature of the data, the potentials of modern science and engineering capabilities are not being used to their fullest. The results obtained by this method of study are not adequately reliable for prediction of successful countermeasures.

By continuing to develop mathematical models of the physical response of the human head and neck to specific impacts, NHTSA has attempted to provide a means of describing the dynamic load-time and stress distribution in the brain, brain stem, and cervical nervous system in the expectation that the actual mechanisms of injury might be discovered. Such mathematical models must, of necessity, be based on complex applied mechanics theory and computational methodologies for which new constitutive equations and definitive physical parameters must be determined. To develop these parameters for the human skull, dynamic testing must be conducted to characterize the material properties of the skull and to validate the response characteristics of the mathematical model. These joint requirements are being pursued in the NHTSA-sponsored human cadaveric system tests (Slattenschek and Tauffkirchen, 1970).

---

[1] Dynamic measurement of aspects of motion (acceleration and velocity) apart from considerations of mass and force.

Study Objectives

Many difficult tasks remain. As examples, the two general topics of head and thoracic injury are discussed below.

Head Injuries. Studies relating detailed knowledge of the crash-induced gross and local movements of the human skull to the movements within the skull that result in injury of the brain should be expedited by use of the recently developed, ultra-high-speed, three-dimensional cineradiography. Tests of cadaveric material using this technique are expected to provide physicians with new insights into the mechanism responsible for the injuries that they find during surgery on vehicle crash victims.

NHTSA expects that the completion of these tasks will allow it:

- to specify injury criteria based on engineering principles to provide more comprehensive and realistic predictors of human injury and
- to develop performance criteria affecting the design of portions of the motor vehicle interior that may be struck by an occupant's head, thereby improving the safety characteristics of the vehicle.

The reduction of head injury would remain an important NHTSA goal even if existing restraint systems should come into full use. There would still be a significant number of head injuries to motor vehicle occupants[1] as well as to pedestrians, cyclists, and occupants of

---

[1] "When all passenger cars have been equipped with passive restraints, [DOT] anticipates a reduction in automobile fatalities approaching 20 percent or approximately 9,000 lives per year assuming 75 percent compliance with air bags and 25 percent with passive belts." (DOT, 1978, p. 11101)

vehicles in which restraints are not required, and occupants of vehicles subjected to side impact and rollover crashes for which current restraints are inadequate.

Thoracic Injuries. NHTSA has supported studies on thoracic injuries in research groups, including universities, in which highly integrated programs of study are being undertaken (Nahum et al., 1970). This multifaceted, multidisciplinary network of research programs is both formally and informally reviewed at national and international forums. The goal of these programs is to provide engineering and medical understanding of trauma to the thorax of the types that occur in motor vehicle crashes as shown by retrospective field experience and laboratory analyses. As in research on head injury, the thoracic program has required the development of new instrumentation for cadaver and animal testing that can be used, as well, in advanced dummies for testing and to assure comparability and integration of results.

The 3-year program of thoracic injury prediction, which was completed in 1978, appears to have provided NHTSA with a basic correlation between the medically accepted scales of injury (AIS) and the mechanical response of the human structure to limited and stylized impact loading. The results of this program, which has depended upon laboratory testing of live animals and human cadavers, should furnish one basis for the development of more sophisticated test dummies which, in turn, would enable NHTSA to write more effective standards.

Other Injuries. The aforementioned tests are not an "end-all" set of tests. Research has not been exhaustive, and the development of more advanced dummies and injury criteria will be only an intermediate step. For example, there still remains the need to develop knowledge of the specific mechanisms of soft tissue injury (Bloom and Duer, 1970), such as aortic rupture. The aortic injury will have to be described in biomechanical terms. A useful and accurate description will depend upon the response characteristics elucidated by the same type of testing discussed above. When known, modifications of the standards will be required to assure reduction of this cause of morbidity and mortality in automotive crashes. Similar analyses for other injury patterns must be developed.

RESEARCH APPROACHES FOR IMPROVEMENT OF SAFETY ON THE ROAD

To assess the utility of data acquired through a number of alternative methods of study, the committee has examined the nature of major research approaches and evaluated the quality of the data derived therefrom. The following section addresses these methodologies individually and comments upon the advantages and disadvantages posed by each. The committee approached each method with the assumption that it is now or could become an appropriately mandated system for the improvement of safety on the road.

In the final portion of this section, the committee addresses the prospect of combining multiple methodologies to reduce the effect of disadvantages that are inherent in each when used alone.

Retrospective Studies

In retrospective studies, accident records are analyzed to determine what types of injury occur, the frequency with which they occur, and the types of crashes with which they are associated. Field observations must be analyzed as thoroughly as possible to estimate preimpact speeds and directions (Lister and Wall, 1970). Accident records, unfortunately, are not as complete as they might be, except when a specially trained crash investigation team prepares them soon after an accident. Even the best documented field studies leave a great deal to be desired as a basis for characterizing the conditions of the crash.

Inferences must then be drawn concerning possible injury-causing mechanisms in the car crash and what modifications can be made to prevent them. Because more than one inference can often be logically drawn from the same set of data, each inference must be tested to determine which one best approximates reality. There are a number of confounding elements in retrospective field analyses. Among them are the complex movements of the car occupant; the movements responsible for the impact that produced an injury; the size, mass, and prior physical condition of the occupant; and many others. Analysis of the complex movements and selection of the critical movement producing injury cannot be consistently derived from a retrospective analysis.

The in-depth crash investigations undertaken by the Department of Transportation now number 6,000. Other studies by investigators in this country and abroad have added an additional 12,000 cases to the files. Although these data have proven very valuable in providing some insights concerning the distribution of injuries and the possible hazards in the motor vehicle interior, the types of accidents, types of vehicles,[1] and other variables are too great to permit an accumulation

---

[1] Distribution of accidents among vehicle types is: passenger cars, 84%; light trucks, 6%; heavy trucks and buses, 8%; motorcycles, 1%; miscellaneous, 1%. (National Center for Statistics and Analysis, U.S. Department of Transportation, 1978).

of quantitative data sufficient to define improved crashworthiness design with confidence.

Nevertheless, retrospective field studies of automobile crashes that are associated with fatalities and injuries remain an essential component of the developmental process. From them, the initial, rough conceptualization of the relationships between the accident and the injury can be formulated. They also provide the final data with which investigators can evaluate any alterations in design, new devices, or other actions taken to reduce mortality and morbidity.

Field Trials of Instrumented Cars

This type of field trial would require fitting a large number (perhaps 70,000 to 100,000) of cars with a variety of instruments to measure force, acceleration, impulse, and other factors, and to put these cars into normal daily use. When an instrumented car is involved in a crash, it would provide precise information that could otherwise only be inferred from retrospective studies. For example, speed and deceleration would be measured with reasonable accuracy, instead of estimated from skidmarks, dirt and debris deposits, crash damage to the vehicle, etc.

It is not clear how such instrument-derived data could be related to improving vehicle crashworthiness. In particular, these measurements on the vehicle would not show what happened to the occupants. Post-accident examination of the occupants and the vehicle interior may suggest how injury occurs, but the detailed mechanisms--and, thus, possible corrective actions--would be elusive. A possible remedy--instrumentation of the occupants--does not appear to be practical.

The amount of data derived from instrumented cars would be of limited statistical significance and could be obtained only at great cost. On the assumption that one out of every 50 cars is involved in an accident each year, 2,000 instrumented crashes a year could be expected from 100,000 instrumented cars. These crashes would represent a large variety of conditions. J. Flora, of the University of Michigan Highway Safety Research Institute, estimated that 87,733 instrumented cars would be necessary to recognize an AIS (accepted scale of injury) change of 1 with greater than 50% certainty (personal communication, 1976). This is not sufficient for drawing general conclusions. The vehicular field data would then have to be supplemented by laboratory experiments in order to correlate them with hypothetical mechanisms of injury.

Finally, adequate instrumentation of the number of vehicles necessary for statistical analysis would be very expensive (possibly several thousand dollars per car), and the turn-around time for obtaining any useful information would be measured in years.

Despite these obvious problems, and the fact that the test population would be the driving public, the concept of instrumenting a limited number of production automobiles should not be dismissed. Information derived from such a program would provide valuable reference data.

Field Trials of Modified Cars

A great many conceivable improvements to the crashworthiness of cars can be imagined on the basis of experience, judgment, and intuition without the need for any lengthy laboratory tests. The question then devolves to determining the most effective modifications among the many that are possible.

NHTSA could fund the modification of the design and/or structure of a very large number, perhaps hundreds of thousands of cars, and then collect statistical information on the efficacy of a modification. To some extent, automobile manufacturers already engage in some such activity, since no design modification can ever be completely tested in a laboratory (Pursel _et al_., 1978; Smith _et al_., 1974). However, the introduction of these modifications by industry is not routinely followed by adequate statistical evaluation of the results, except perhaps as repair rates or egregious safety defects make failures apparent. The lack of routine comprehensive follow-up of the effects of modifications appears due to the prohibitive costs of such activities.

The major defect of this approach is that the American driver is its test subject. Many people would object to a plan to do this intentionally. However, the approach is similar to that regularly used in the clinical evaluation of new drugs and therapeutic techniques. If no one is denied what is already considered to be an acceptable level of protection, there should be no moral objection to the use of the human being as the test subject. The purpose would be to evaluate the relative safety improvements effected by various possible modifications.

It is not clear how modifications would be selected for such testing, although NHTSA would presumably develop a proposal based on all available data and analyses. Nor is it clear that the current mandate to NHTSA would permit new rulemaking for safety designs without clear-cut performance standards.

A significant limitation of this approach is the length of time that would be required to obtain conclusive results. While our citizens are testing car modifications over 2 or 3 years, a great many of them will be victims of accidents. The injuries incurred might have been avoided or reduced in severity by prior laboratory testing. Nevertheless, this approach should not be rejected.

Human Volunteers

Because tests using human subjects would provide the most accurate representation of an actual crash situation, the use of volunteers should be considered. However, the need to avoid injury precludes testing at crash severities that produce injury to motor vehicle occupants. Volunteers may be useful in limited, low-level load studies which, for example, might include studies of the effect on muscle tone (a dynamic response) and on low-level impairment of consciousness, as found in some contact sports. The resulting data are useful in the evaluation of surrogates for humans when tested at comparable low-level impacts.

Volunteer studies will continue to be necessary, but must be limited to non-injury-producing impact severities to validate the lower ends of data scales developed by other means. Without additional types of data (as discussed by Wisner et al., 1970), extrapolation from such low-level load studies would probably not produce adequately predictive information for the high load levels that are associated with injury and death.

Animal Testing

Tests with animals can be conducted into the injury range and the injuries can be documented post-mortem. In contrast to tests with volunteers, instrumentation can be surgically implanted in these tests. Data derived from such experiments can be used to determine the constitutive relationships necessary to develop advanced analytical and mechanical models of human beings.

The effective use of animal data is limited because scaling of results to humans is prevented by the great interspecies anatomical and biomechanical differences. Even higher primates do not simulate the geometry of specific human body areas and parts, and experience with animal injuries does not correlate satisfactorily with human injuries (Cherry *et al.*, 1978; Ommaya *et al.*, 1967, 1971). Nevertheless, animal studies are useful supplements to other modes of study, even though they cannot be used as exclusive sources of data. For example, animals can be used to compare mechanical response characteristics and injuries between live animals and matched cadaveric animals under identical test conditions. This type of study can be used to evaluate the degree to which a human cadaveric specimen can be relied upon to simulate the movements and injuries sustained during life. Further, this type of analysis can reveal the weaknesses of a cadaveric test system and suggest methods for ameliorating the deficiencies.

While important for developing an understanding of the physiopathologic mechanism of tissue damage, animal models fail to provide quantitative data directly applicable to two essential aspects of the problem in humans: the kinematics of the human during impacts and the distribution of stress-strain profiles within the tissues of interest.

Mathematical Models

Another approach is the mathematical model. Conceptually, one can mathematically model the vehicle occupant and the interaction of the occupant with the vehicle during a crash. Such models are advantageous in that their performance is repeatable. Thus, they can be used efficiently to evaluate the effects of the systematic variation of one or more parameters. The inherent disadvantage of these models is that the occupant, as well as the vehicle, must be defined in analytical terms. To attain realism in the model, the basic constitutive relationships and mathematical equations defining the model must be truly descriptive of human and vehicle characteristics. This requires far more extensive measurements of human and vehicle responses than are now available.

Although there are sufficiently sophisticated mathematical and computer procedures with which to address the problem, there are no adequate mechanical data resources for selection of parameters to be included in models. To confound this, well-conceived experiments for validation of existing models are also in short supply (Robbins et al., 1970). In addition, only rudimentary attempts have been made by modelers to assure that the available biomechanical data base is a sufficient foundation on which to model with confidence.

The problem of model development is directly parallel to the problem of dummy development. They both draw on the same set of basic human information and they must both reflect the same laws of physics.

Human Cadaver Research and the Anthropomorphic Dummy

Federal motor vehicle safety standards concerned with occupant protection have relied upon limited scientific data generated from analyses of animal and human cadaver injuries sustained as a result of controlled impacts simulating crash conditions. These data, generated from a limited number of tests (Nahum et al., 1970), have been used to define injury criteria for evaluating anthropomorphic dummy test data and, to a limited degree, to define humanlike response characteristics for designing dummies. At the present stage of development, anthropomorphic dummies used to assess the protective nature of designs to meet safety standards do not have sufficiently well-defined biomechanical bases. However, even the present dummy test technology could not have been developed without cadaver experimentation (Snyder, 1973).

The limitations of the present dummy design are many (Foster et al., 1977; McElhaney et al., 1973; O'Connell et al., 1977; Roshala, 1974). The structures of the face and head bear only an external resemblance to the human, and they contain no surrogate structures for the brain or facial bones. The neck bears no resemblance to the human in forward, backward, side-to-side, or rotational movement. The chest, including both the thoracic wall and the internal soft structures and organs, must be significantly redesigned with increased instrumentation to document the forces and accelerations that cause serious injuries in these vital areas of the body. The lower torso requires alteration in mobility characteristics and in posture. The mass distributions and joint structures of the arms and legs should be improved so that they are more comparable to humans (Kroell et al., 1976). Presently, the thoracic vertebral column is a rigid system that may require extensive redesign, not only to provide an adequate model for vertebral and spinal injury prediction but also to provide a realistic system to interconnect other body parts.

Despite the limited characterization of the human embodied in the present generation of dummies, much useful information has been obtained by using these test devices (Brinn, 1972; Chandler, 1973; Haselgrave, 1974; and Roshala, 1974).

The committee believes that an improved anthropomorphic dummy for actual crash testing experiments is an essential link in the determination of more effective motor vehicle safety standards. To develop a significantly improved dummy that will more closely approximate human movements in motor vehicle crashes, the committee considers it reasonable and pertinent that further studies on human cadavers be pursued to provide data bases for surrogate development.

The preceding statement is made with full realization of the limitations of human cadaver research. The cadaver tends to be structurally comparable to its living counterpart, but lacks its physiological dynamics, e.g., the pulsating pressure within the vascular bed and the respiratory movements of the lungs and chest wall. In addition, the muscle tone and its reactions in emergency situations are not representative.

Nevertheless, the need for the closest possible approximation of the living human in order to develop injury criteria and to design a useful dummy appears to be met principally by human cadaver research. The data acquired from cadavers must be supplemented and modified by other methodologies to achieve the simulation of living humans that can provide the necessary information for development of vehicle safety standards.

Approaches to Reducing Mortality and Morbidity Other Than by Improving Crashworthinesss of Motor Vehicles

An analysis of the classical, theoretically effective, and cost-effective means of reducing highway mortality and morbidity can be subdivided conveniently into three general modes:

- modification of vehicles to make them more "crashworthy";
- modification of the behavior of drivers to reduce activities which are associated with, and presumably lead to, accidents; and
- modification of the highway environment to provide systems that would reduce the likelihood and severity of motor vehicle accidents.

Indeed, any one of these approaches could reduce death and injury rates. The second and third items are discussed below. The first one has been addressed in detail in the preceding sections.

Behavior Modification.

Modifying human behavior is difficult, particularly when regulations imposed by governmental authority appear to conflict with individual or societal assumptions regarding individual freedoms, especially those involving choice of a life style and its attendant behavioral characteristics. With regard to automobile safety, it has long been assumed that driving under the influence of alcohol will result in more frequent and more serious accidents (Allsop, 1966). It would follow that the practical control of the drinking driver would reduce the rate of accidents--hence, the mortality and morbidity rates. In Great Britain, after severe penalties were introduced for driving under the influence of alcohol, there was an initial reduction in motor vehicle accidents, injuries, and death (Roberts, 1971). More recent data indicate an absence of continuing effect (Ross, 1973). Although not clearly explained, the causes of the failure to maintain the reduction in accident rates may be due to relaxation of law enforcement and imposition of the penalties or to a return to former driving habits. This explanation would indicate that social acceptance of regulation is inadequate to meet the problem. The data describing the experience in Sweden following the passage and implementation of severe drinking-driving laws show that the legal strictures had no effect on severe accidents (Ross, 1975).

In the United States, the very high rate of alcohol consumption among drivers of motor vehicles involved in accidents leading to injury and death (Allsop, 1966; DOT, 1977b) and the comparatively weak penalties imposed for such behavior (DOT, 1975) suggest that this mode of behavioral modification may be impractical in our society, however desirable.

Similarly, restraint devices have failed in their purpose because of a very low usage rate. Approximately 20% of drivers currently use the belt restraint systems that are installed in automobiles (Anderson, 1971; DOT, 1977a).

The committee believes that at present there are no socially acceptable methods for altering driver behavior that will produce the desired level of protection from injury and death.

In addition to the social limitations of behavioral modification, there are certain technical limitations. Under optimal conditions for behavioral modification (i.e., a motivated subject, a relatively simple behavior, relative isolation from distraction, and prolonged and repeated exposure to the modifying paradigm), persisting changes in behavior cannot be produced without repeated application of the paradigm. It is, therefore, difficult to envisage any significant long-lasting change in the highly complex behavior of drivers within the present stage of knowledge of behavioral modification.

The education and training of the young driver before his behavior patterns have become fixed in an und sirable mode is one behavioral modification system that has had an impact. The relationship between early driver education and accidents is reflected in the lower insurance premium rates that have been established for those who have gained from such experience.

Another form of behavioral modification that has achieved a degree of success can be recognized by the reduction in accident rates that occurred with the imposition of lower speed limits on the highway. The long-term effectiveness of this system will depend upon the level of driver compliance.

The committee concludes that research in the field of behavioral modification, with specific application to the "problem driver," continues to be necessary.

Highway Improvement. The safety design of highways has been improved progressively, especially in the national interstate highway network. Existing designs for improvement are limited only by the practical application of present techniques. Continued development of designs for improving the safety of the general road environment is necessary. In the future, it may be possible to have vehicles controlled by instruments to assure safer vehicular traffic, but such a major change would require several decades for research design and implementation. This system would be very costly.

* * *

In summary, altering the behavior of vehicle drivers, though desirable, seems unlikely to succeed under present conditions. On the other hand, education and training as preventive measures, prior to the development of poor driver behavior, are clearly necessary and practical. Highways have been altered, but further improvement requires research and application. These alternatives offer, at least in theory, the hope of dramatic reduction in vehicular trauma, but have severe practical limitations.

SUMMARY OF ALTERNATIVE APPROACHES TO CRASHWORTHINESS RESEARCH

The mandated goal of the programs of the National Highway Traffic Safety Administration (NHTSA) is to reduce traffic deaths and serious injuries. Sufficient information must be obtained about the interaction of living human occupants and their vehicles in order to design systems to effect such reductions. There are several routes for the development of information about such relationships, none of which is sufficient by itself. The group of sources of relevant data includes animal tests with scaling towards humans, mathematical models, retrospective field studies of accidents, anthropomorphic dummy tests, human cadaveric tests, intuitive insights, and field testing of vehicles.

To understand fully the insufficiency of any one of the above, let us assume that the present-generation (Part 572) dummy provides adequate humanlike gross torso kinematics in an accident. The same dummy would be of limited value in studying the movement of the arms in the crash and totally inadequate for studies of vascular effects because it has no surrogate vascular system. An animal test might produce more information about vessels, but little about gross body kinematics. Further, at the present state of the art, computerized mathematical models, which could predict vehicle-occupant interactions during an accident with confidence, are presently beyond reach. Similarly, although engineering judgment might yield some good answers, the majority would be reached by using an incomplete list of medical/engineering variables as if it were complete. This would lead to an oversimplification in dummy design.

Cadavers used as models that can be used in severe crash situations to which living humans could not be exposed seem to be essential elements in the process that will produce more lifelike dummies and injury criteria, thereby reducing the continued need for cadaveric models. As the dummy improves, the need for cadavers lessens. It is the committee's opinion that the mandate of NHTSA to reduce death and injuries resulting from motor vehicle crashes cannot be fulfilled without this valuable tool. But it cannot be fulfilled with this tool alone. Neither the cadaver nor any one of its alternatives is sufficient in and of itself; all are necessary if human life in traffic accidents is to be made more secure.

REFERENCES

Allsop, R. E. 1966. Alcohol and Road Accidents. RRL Report No. 6, Road Research Laboratory, Ministry of Transport, Harmondsworth, England. 48 pp.

Anderson, T. E. 1971. Shoulder Belt Utilization. The University of North Carolina Highway Safety Research Center, Chapel Hill, N. C., 21 pp.

Backaitis, S., and E. Enserink. 1977. Repeatability of setup and stability of anthropomorphic landmarks and their influence on impact response of automotive crash test dummies. SAE #770260. International Automotive Engineering Congress and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-Mar. 4, 1977. Society of Automotive Engineers, Inc., Warrendale, Pa. 24 pp.

Bloom, A., and R. W. Duer. 1970. An engineering approach to trauma indicating organs. SAE #700407. Pp. 876-878 in 1970 International Automotive Safety Conference Compendium. Society of Automotive Engineers, Inc., New York, N.Y.

Brinn, J. 1972. Hazard indices and their relationship to anthropomorphic dummies. SAE #720441. Presented at the 2nd International Conference on Passive Restraints, Detroit, Mich., May 22-25, 1972. Society of Automotive Engineers, Inc., New York, N.Y. 8 pp.

Chandler, R. F. 1973. Evaluation of crashworthiness test data. SAE #730290. Pp. 1031-1039 in Business Aircraft Meeting, Wichita, Kans., Apr. 3-6, 1973. Society of Automotive Engineers, Inc., New York, N.Y.

Chandler, R. F., and R. A. Christian. 1970. Crash testing of humans in automobile seats. SAE #700361. Pp. 112-132 in 1970 International Automobile Safety Conference Compendium. Society of Automotive Engineers, Inc., New York, N.Y.

Cherry, L. M., S. M. Case, and A. C. Wilson. 1978. Frog perspective on the morphological difference between humans and chimpanzees. Science 200:209-211.

Foster, J. K., J. O. Kortge, and M. J. Wolanin. 1977. Hybrid III: Biomechanically based crash test dummy. SAE #770938. Pp. 975-1013 in 21st Stapp Car Crash Conference Proceedings, Oct. 19-21, 1977, New Orleans, La. Society of Automotive Engineers, Inc., Warrendale, Pa.

Goldsmith, W. 1966. The physical processes producing head injuries. Pp. 350-382 in Head Injury Conference Proceedings. J. B. Lippincott Co., Philadelphia and Toronto.

Goldsmith, W. 1978. Some aspects of head and neck injury and protection. Paper to be presented at the NATO Advanced Study Institute: Progress in Biomechanics, July 10-21, 1978.

Haslegrave, C. M. 1974. Dummies for crash testing of motor cars. Appl. Ergon. 5 (3):153-160.

Hodgson, R. R. 1972. Head model for impact tolerance. Pp. 113-128 in W. F. King and H. J. Mertz, eds. Proceedings of the Symposium on Human Impact Response held at the General Motors Research Laboratories, Warren, Mich., October 2-3, 1972. Plenum Press, N.Y.-London.

Khalil, T. B., W. Goldsmith, and J. L. Sackman. 1974. Impact on a model head. Int. J. Mech. Sci. 16:609-625.

Kroell, C. K., D. C. Schneider, and A. M. Nahum. 1976. Comparative knee impact response of Part 572 dummy and cadaver subjects. SAE #760817. Pp. 583-606 in 20th Stapp Car Conference Proceedings, Oct. 18-20, 1976, Dearborn, Mich. Society of Automotive Engineers, Inc., Warrendale, Pa.

Kyropoulos, P., and R. W. Roe. 1970. State-of-the Art--Anthropometry. SAE #700356. Pp. 45-51 in 1970 International Automobile Safety Conference Compendium. Society of Automotive Engineers, Inc., New York, N.Y.

Lister, R. D., and J. G. Wall. 1970. Determination of injury threshold levels of car occupants involved in road accidents. SAE # 700402. Pp. 818-833 in 1970 International Automobile Safety Conference Compendium. Society of Automotive Engineers, Inc., New York, N.Y.

Massing, D. E. 1977. Performance evaluation of three new-generation anthropomorphic test dummies. SAE #770261. International Automotive Engineering Congress and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-Mar. 4 1977. Society of Automotive Engineers, Inc., Warrendale, Pa. 16 pp.

McElhaney, J. H., P. I. Mate, and V. L. Roberts. 1973. A new crash test device: Repeatable Pete. SAE #730983. Pp. 467-507 in 17th Stapp Car Crash Conference Proceedings. Society of Automotive Engineers, Inc., New York, N.Y.

Nahum, A. M., C. W. Gadd, D. C. Schneider, and C. K. Kroell. 1970. Deflection of the human thorax under sternal impact. SAE #700400. Pp. 797-807 in 1970 International Automobile Safety Conference Compendium. Society of Automotive Engineers, Inc., New York, N.Y.

O'Connell, O., G. George, R. Almquist. 1977. A survey concerning the quality of Part 572 Hybrid II dummies as measuring instruments for crash testing. SAE #770263. International Automotive

Engineering Congress and Exposition, Cobo Hall, Detroit, Warrendale, Pa. 20 pp.

Ommaya, A. K., and T. A. Gennarelli. 1976. Physiopathologic basis for noninvasive diagnosis and prognosis of head injury severity. Pp. 49-75 in R. L. McLauren, ed. Head Injuries. Grune & Stratton, Inc., New York, N.Y.

Ommava, A. K., and A. E. Hirsch. 1971. Tolerance of cerebral concussion from head impact and whiplash in primates. J. Biomech. 4:13-22.

Ommaya, A. K., P. Yarnell, A. E. Hirsch, and E. H. Harris. 1967. Scaling of experimental data on cerebral concussion in subhuman primates to concussion threshold for man. SAE #670906. Pp. 47-52 in 11th Stapp Car Crash Conference Proceedings, Anaheim, Calif., Oct. 10-11, 1967. Society of Automotive Engineers, Inc., New York, N.Y.

Pursel, H. D., R. W. Bryant, J. W. Scheel, and A. J. Yanik. 1978. Matching case methodology for measuring restraint effectiveness. SAE #780415. Society of Automotive Engineers, Inc., Warrendale, Pa.

Roberts, H. J. 1971. Pg. 447 in The Causes, Ecology and Prevention of Traffic Accidents. Charles C. Thomas, Springfield, Ill.

Robbins, D. H., R. O. Bennett, A. W. Henke, and N. N. Alem. 1970. Predictions of mathematical models compared with impact sled test results using anthropomorphic dummies. SAE # 700907. Pp. 299-328 in 14th Car Conference Proceedings, Ann Arbor, Mich., Nov. 17-18, 1970. Society of Automotive Engineers, Inc., New York, N. Y.

Roshala, J. L. 1974. Testing crash dummies. Automot. Ind. 151(8):41-44.

Ross, H. L. 1973. Law, science, and accidents: the British Road Safety Act of 1967. J. Legal Studies 11:1-78.

Ross, H. L. 1975. The Scandanavian myth: the effectiveness of drinking-and-driving legislation in Sweden and Norway. J. Legal Studies 4(2):285-310.

Slattenschek, A., and W. Tauffkirchen. 1970. Critical evaluation of assessment methods for head impact applied in appraisal of brain injury hazard, in particular in head impact on windshield. SAE #700426. Pp. 1084-1112 in 1970 International Automobile Safety Conference Compendium. Society of Automotive Engineers, Inc., New York, N.Y.

Smith, G. R., E. C. Gulash, and R. G. Baker. 1974. Human volunteer and anthropomorphic dummy tests of General Motors driver air cushion system. SAE #740578. Pp. 212-226 in Proceedings of the International Conference on Occupant Protection, Troy, Mich., Jul. 10-12, 1974. Society of Automotive Engineers, Inc., New York, N.Y.

Snyder, R. G. 1970. State-of-the Art--Human impact tolerance. SAE #700398. Pp. 712-782 in 1970 International Automobile Safety Conference Compendium, Society of Automotive Engineers, Inc., New York, N.Y.

Snyder, R. G. 1973. Technique for establishing tolerance to impact. In Biomechanics and Its Application to Automobile Design. SAE # P-49, 19 pp.

Society of Automotive Engineers. 1975. Human tolerance to impact conditions as related to motor vehicle design--SAE J885a; SAE information report. Pp. 34.75-34.78 in SAE Handbook 1975. Society of Automotive Engineers, Inc., Warrendale, Pa.

U.S. Department of Transportation. 1977a. Final rule. Part 571--Federal motor vehicle safety standards. Fed. Regist. 42:34289-34305, July 5, 1977.

U.S. Department of Transportation. 1977b. Pg. III.1.2 in Fact Book: Statistical Information on Highway Safety. National Center for Statistics and Analysis, Washington, D.C.

U.S. Department of Transportation, National Highway Traffic Safety Administration. 1978. Five year plan for motor vehicle safety and fuel economy rulemaking. Fed. Regist. 43 (52):11100-11107, March 16, 1978.

U.S. Department of Transportation, National Highway Traffic Safety Administration, Planning and Evaluation. 1975. Statewide Highway Safety Program Assessment. A National Estimate of Performance, July 1975. U.S. Department of Transportation, Washington, D.C. 147 pp.

Wisner, A., J. Leroy, and J. Bandet. 1970. Human impact tolerance. Pp. 783-796 in 1970 International Automobile Safety Conference Compendium, SAE #700399. Society of Automotive Engineers, New York, N.Y.

Annex A

WORKSHOP PRESENTATION, NHTSA

May 18, 1978

9:30 - 9:45	A.	Introductory Remarks - Howard Dugoff
9:45 - 10:30	B.	Legislative - Karen Dyson
		1. Safety Legislation
		2. Legal Criteria for Rulemaking
		3. Types of Legal Challenges to Rules
		4. Role of the Dummy from a Legal Standpoint
11:15 - 12:30	C.	Rulemaking - Ralph Hitchcock
		1. Rulemaking Priorities
		2. The Rulemaking Process
		3. Requirement for a Surrogate from a Rulemaking Standpoint
		4. The Side Impact Rule - August Burgett
		5. The Pedestrian Rules - Tom MacLaughlin
		6. The Advanced Crashworthiness Rules - Leon DeLarm
2:00 - 2:30	D.	Accident Statistics - Russell Smith
		1. Present Sources of Data and Precision
		2. Planned Sources of Data
		3. Summary of Capability for Accident Reconstruction
2:30 - 5:30	F.	Advanced Dummy Development - Kennerly Digges, Rolf Eppinger

NHTSA-Sponsored Research Programs

TITLE: Occupant Side Impact Simulations Using Crash Victim Simulator (CVS) Program

Objective:

Development of computer side impact models of dummy, cadaver, and living human based on existing experimental results and using existing gross motion CVS computer program.

Application:

Performance of parametric and optimization studies for the development of side impact protection systems/devices.

Provision of guidelines to define dummy performance characteristics for input into compliance test device for FMVSS 214.

TITLE: Injury Study of the Femur-Pelvic Complex

Objective:

Identification of the various impact injuries sustained in the knee-femur-pelvic complex for both the frontal and side collision modes.

Identification of the physical descriptors that can be used as adequate and reliable indicators for injury protection and development of a quantitative relationship between three physical descriptors and injury severity.

Application:

Establishment and upgrade of injury tolerance level/injury criteria of the knee-femur-pelvic subsystem for frontal and side impacts-FMVSS 214,208.

Provision of data for the design of a test dummy with improved biofidelity.

TITLE: Head Model Injury Criteria Development

Objective:

Development of a model that will predict head injury when the head is subjected to impacts and accelerations similar to those experienced by motor vehicle occupants, motorcyclists, and pedestrians in crashes.

Application:

Exercise of the model will assist in the preparation of valid head injury criteria for all situations selected for rulemaking. Utilize in the development and assessment of head protection devices, helmets, padding, etc.

TITLE: Investigation of Impact Biodynamics

Objective:

Measurement of noninjurious forces acting directly on volunteers and measurement of their mechanical responses to these lateral forces.

Application:

The above measurements will provide fundamental data to verify the biofidelity of dummies in terms of mechanical responses.

TITLE: Mass Distribution Characteristics of Living Human Beings

Objective:

Collection of data on the mass distribution of adult males.

Application:

The data will be used in the design of adult male dummies with improved biofidelity of mass distribution.

TITLE: Mass Distribution Characteristics of Children

Objective:

Collection of data on the mass distribution of 3- to 6-year-old children.

Application:

The data will be used in the design of child dummies with improved biofidelity of mass distribution.

TITLE: Response of Human Surrogates in Side Impact

Objective:

Measurements of lateral forces acting directly on human cadavers and measurement of their mechanical response to these lateral forces plus assessment of any injury.

Application:

The measurements described above will provide fundamental data to verify the biofidelity of dummies in terms of mechanical response. Injuries that may occur will also be correlated with the mechanical response.

TITLE: Mass Distribution of Adult Humans II

Objective:

Collection of data on the mass distribution of women so that a female model can be developed from the CVS program.

Application:

The female model will be utilized to generate design data for a female dummy suitable for compliance test procedure and experimental evaluation of female responses in crash protective systems as part of the development of protection for the total at-risk automotive crash population.

TITLE: Kinematic and Kinetic Characterization of the Human Neck

Objective:

Generation and analysis of the head's motion with respect to T-1 of volunteers exposed to frontal, lateral, and oblique accelerations.

Application:

Definition of performance corridors for dummy neck design.

TITLE: Quantification of Thoracic Response and Injury

Objectives:

Quantification of the kinetic and kinematic response of the human thorax to impact in rigorous engineering terms.

Derivation and compilation of a compendium of predictive functions that relate specific kinematic parameters of thoracic impact with injury.

Definition of adequate performance specifications to insure kinetic and kinematic similitude between a surrogate thorax and that of a human thorax.

Application:

Direct input to program to design test device for FMVSS 214 and 400 series.

TITLE: Quantification of Occupant Response and Injury from Impact

Objectives:

Generation of response and injury data to supplement previous effort using cadaveric specimens in the automotive crash environment.

Application:

Add to statistical validity of thoracic injury criteria and dummy design specifications.

TITLE: Kinesiology of the Human Shoulder and Spine

Objectives:

Derivation of adequate biomechanical specifications of human spine and shoulder for front, oblique, and lateral crashes.

Analyses of data to identify significant kinematic and kinetic parameters.

Proposal of mechanical analogs that mimic the significant specifications.

Design, construction, testing, evaluation of actual devices of both structures.

Application:

Direct utilization in advanced dummy device.

TITLE: Brain Injury Indicators in Whiplash Motions

Objective:

Application of a series of accurately controlled mechanical inputs to the heads of primates. Extensive monitoring of physiological response and documentation of neuropathology are performed to allow development of relationships between the mechanical parameters that define the head motion and the various parameters that quantify head injury.

Application:

Utilization in the development of a head injury criteria, including closed head injury.

TITLE: Compliance Characteristics of the Human Thorax During Cardiopulmonary Resuscitation

Objective:

Determination of the force-deflection characteristics of human thorax.

TITLE: Evaluation of 572 Dummy

Objective:

Examination repeatability of 572 dummy in lateral and oblique impact modes.

Application:

The 572 dummy may be required for use in compliance test procedures in which other than head-on impacts are simulated.

TITLE: Fatal Neck Injury Study

Objective:

Determination of whether the helmet when worn by a motorcyclist has some effect on the probability of occurrence of neck injury resulting from a crash.

Application:

Ascertainment of whether there is merit to the arguments presented by helmet law opponents that helmets contribute to neck injuries.

TITLE: Measures of Head Accelerations of Boxers

Objective:

Determination of the feasibility of utilization of mouthpiece accelerometers-transmitter for boxers' use.

Application:

If a protocol can be established permitting measurement of accelerations of boxers' heads during a knockout or severe head blow, then a project will be undertaken to take such measures.

TITLE: Computerization of Head/Neck Information

Objective:

Development of a standardized procedure for brain/neck lesion identification suitable for computer entry.

Application:

A standardized procedure for brain/neck lesion identification. Quantification for computer entry will permit researchers to compare trauma data from the clinical (CAT Scan) with the autopsy for injury tolerance research purposes.

TITLE: Crash Victim Simulator Data

Objectives:

Experimental determination of the torque characteristics for the shoulder, knee, hip, elbow, and ankle for using adult volunteers.

Incorporation of data sets into the parameter base of the CVS computer program for 3- and 6-year-old children.

Applications:

Use of the CVS program and associated models as tools to assist in designing dummies and evaluating protection concepts.

TITLE: Data for Validation of Crash Victim Simulator

Objective:

Performance of a series of replicate sled tests to obtain data for validation of a model that will be developed and implemented into the CVS computer program under a separate contract, No. DOT-HS-6-01300.

Application:

Use of the CVS Program as a tool to assist in designing dummies and evaluating protection conepts.

TITLE: Validation of Crash Victim Simulator

Objectives:

Development of computer models and the CVS computer program to a level where they can be used for a variety of rulemaking activities with respect to the CVS program.

Add user convenience to facilitate the three items that follow:

Measurement of a dummy's characteristics and implementation of a mathematical model of it by developing input to the CVS program.

Perform and simulate dummy component validation tests.

Simulate sled tests conducted under another contract, No. DOT-HS-7-01660, to establish confidence at the system level.

Application:

Use of the CVS Program as a tool to assist in designing dummies and evaluating protection concepts.

TITLE: Development of Approximating Solutions for CVS Program and Dummy Design Information

Objectives:

Development, evaluation, and recommendation of means for evaluating accuracies and sensitivities of various "response measures" to the choices and values of defining parameters for crash victim simulators.

Making a series of simulations using a "general purpose" computer program, the CVS.

Computation of various "response measures" and "response comparative measures".

Development of computer software to facilitate this.

Application:

Use of the CVS program and other software as tools to assist in designing dummies and evaluating protection concepts.

TITLE: Anatomical Cross-Sectional Geometry

Objectives:

Obtaining accurate cross-sectional anatomical descriptions of the child.

Development of inertia tensors and masses for the major anatomical components so that a child kinematic model can be constructed from the CVS computer program.

Development of software to generate meshes for finite element models of various organs and anatomical components.

Applications:

Child gross motion CVS model will be validated and exercised to assist in the development of construction plans for a child dummy and preliminary evaluation of optimal restraint systems.

Finite element models of anatomical components can be developed, using results of this contract to generate the finite element meshes and mass matrices. The finite element models could be used either directly to predict the internal biomechanical responses and injuries associated with a crash environment design, or indirectly to search for empirical injury relations by repeated exercises of the models.

TITLE: Further Development of Thorax Program

Objective:

Continuation of development of the finite element injury model of the rib cage to include quasi-static response and novel shell elements to increase and permit more efficient and powerful computations of chest impact problems.

Application:

Prediction of chest cage injury via computer in crash impact situations for evaluation of protective concepts.

TITLE: Contact Impact Problems

Objective:

Development of ccurate and efficient numerical capability to solve a broad class of contact impact problems involving impact effects, large deformations, and as many as three dimensions.

Application:

Computation of interactive loads that are developed between contacting bodies for a variety of situations, e.g., any anatomical components (including internal components), air bags contacting any other objects, tires contacting pavement, and two vehicles colliding.